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 CONCERNING A FILING UNDER 35 U.S.C. 371

International Application No. I/GB99/01763	International Filing Date June 4, 1999	Priority Date Claimed June 5, 1998
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**Title of Invention:** IMAGING ARRANGEMENT AND METHOD

**Candidate(s) For Mark John RICHES, Roger James Frost WILSON, and Brian Arthur CANT**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

- . [X] This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
- . [ ] This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.
- . [ ] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
- . [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
- . [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
  - a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. [ ] has been transmitted by the International Bureau.
  - c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
- . [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
- . [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
  - a. [X] are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. [ ] have been transmitted by the International Bureau.
  - c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
  - d. [ ] have not been made and will not be made.
- . [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
- . [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
- . [ ] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11. to 16. below concern other document(s) or information included:**

- 11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
- 12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
- 13. [ ] A FIRST preliminary amendment.
- [ ] A SECOND or SUBSEQUENT preliminary amendment.
- 14. [ ] A substitute specification.
- 15. [ ] A change of power of attorney and/or address letter.
- 16. [X] Other items or information:
  - a. [ ] Verified Small Entity Statement.
  - b. [ ] Copy of Notification of Missing Requirements.
  - c. [X] Cover sheet of WIPO publication (W0 99/64911) (1-sheet).

PLICATION NO.

INTERNATIONAL APPLICATION NO.  
PCT/GB99/01763ATTORNEY DOCKET NUMBER  
03042.006009/701559

[X] The following fees are submitted:

## Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EPO or JPO.....\$860.00  
International preliminary examination fee paid to

USPTO (37 CFR 1.482).....\$690.00

No international preliminary examination fee paid to

USPTO (37 CFR 1.482) but international search fee  
paid to USPTO (37 CFR 1.445(a)(2)).....\$760.00Neither international preliminary examination fee  
(37 CFR 1.482) nor international search fee  
(37 CFR 1.445(a)(2)) paid to USPTO.....\$1,000.00International preliminary examination fee paid to USPTO  
(37 CFR 1.482) and all claims satisfied provisions  
of PCT Article 33(1)-(4).....\$ 100.00

ENTER APPROPRIATE BASIC FEE AMOUNT = \$ 860.00

Surcharge of \$130.00 for furnishing the oath or declaration later than  
[ ] 20 [ ] 30 months from the earliest claimed priority date  
(37 CFR 1.492(e)).

\$

Claims	Number Filed	Number Extra	Rate	
Total Claims	39 -20=	19	X \$18.00	\$ 342.00
Independent Claims	6 - 3=	3	X \$80.00	\$ 240.00
Multiple dependent claim(s) (if applicable)			+\$270.00	\$ 270.00

TOTAL OF ABOVE CALCULATIONS = \$ 1712.00

Reduction by 1/2 for filing by small entity, if applicable.

\$

SUBTOTAL = \$ 1712.00

Processing fee of \$130.00 for furnishing the English translation later  
than [ ] 20 [ ] 30 months from the earliest claimed priority date  
(37 CFR 1.492(f)).

+

TOTAL NATIONAL FEE = \$ 1712.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The  
assignment must be accompanied by an appropriate cover sheet  
(37 CFR 3.28, 3.31).

\$40.00 per property + \$

TOTAL FEES ENCLOSED = \$ 1712.00

Amount to be	
refunded	\$
charged	\$

a. [X] A check in the amount of \$ 1712.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. \_\_\_\_\_ in the amount of

\$ \_\_\_\_\_ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees  
which may be required, or credit any overpayment to Deposit Account  
No. 06-0916. A duplicate copy of this sheet is enclosed.

The Commissioner is hereby authorized to charge any other fees due under 37 C.F.R. §1.16  
or §1.17 during the pendency of this application to our Deposit Account No. 06-0916.

Ernest F. Chapman  
Reg. No. 25,961

Submitted: December 5, 2000

The PTO ~~does not~~ receive the following  
listed item(s) \_\_\_\_\_

check \$ 1,676.00

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Imaging Arrangement and Method

The present invention relates to an imaging arrangement and method, particularly to an arrangement and method for high speed imaging, typically taking a sequence of pictures at frame rates in excess of 1000/second. The invention also relates to an electro-optical device for use in such an arrangement.

Many applications require imaging at frame speeds in the range from approximately 2,000 frames/sec to 100,000,000 frames/sec. These include analysis of lightning, sparks resulting from electrical discharge, shock waves, fuel injection and fluid dynamics. Conventional film and video systems are convenient and usually reasonably priced but are only capable of frame rates of up to approximately 100,000 frames/sec (fps).

At ultra high speed (greater than 100,000 fps) a beam splitter or rotating mirror/prism is typically employed together with some shuttering arrangement to record the image at a succession of different physical locations at consecutive points in time. The actual recording can be performed, for example, using conventional film or charge-coupled device (CCD) cameras.

The drawback with film and video techniques is that the systems are usually very clumsy, film systems relying on rotating mirrors or prisms which give limited flexibility in exposure times and frame rate. The cost of developing film can also be very high. Moreover the frame rate must be set for, and cannot be varied during, each "run".

An electronic technique using a multiple camera approach is described in International patent application publication number WO 95/14951 in which a beam-splitter generates 8 images which are applied to eight different cameras. These cameras may be gated in

sequence to capture images at extremely high rates indeed. A wide selection of exposure time and frame rate can usually be made with such an arrangement. A limited number of frames is admittedly provided but this is seldom a drawback in the applications to which such imaging systems are put. Apart from sheer size, the main drawback of such an arrangement is cost. Using 8 optical gates (intensifiers) and 8 CCD cameras, such an imaging system might cost £200,000.

The present invention has for its object to provide a less expensive arrangement and method suitable for capturing high speed events.

According to a first aspect of the present invention there is provided an electro-optic device comprising a photosensitive surface which surface is arranged to comprise a plurality of independently-gatable portions.

The invention also comprises an imaging arrangement for two dimensional optical data represented by at least two beams of electromagnetic radiation, the arrangement comprising: means for gating and converting the beams into image data, which means for gating and converting the beams into image data includes a single electro-optic device according to the first aspect of the invention, wherein the independently-gated portions corresponding to each of the plurality of beams.

Two dimensional optical data will typically comprise a conventional optical image, but not necessarily so.

In one embodiment, the electro-optic device comprises an image intensifier. The image intensifier conveniently has a divided photocathode in which each divided portion may be gated independently. Typically the independently-gated portions comprise separate conductive segments of a layer adjacent a conventional photocathode which typically has extremely high resistivity. A single camera may be used to provide a particularly low cost arrangement although a number of cameras, could be used if desired. While

the imaging apparatus may be applied to a film camera, in a preferred embodiment a solid state imager is provided.

The term "solid state imager" as used herein is intended to encompass a variety of electronic array sensors such as CCD (Charge Coupled Devices), CID (Charge Injection Devices), MOS and CMOS (Complementary Metal Oxide) and amorphous silicon devices.

Alternatively the electro-optic device comprises a solid state imager divided into separately-gatable portions. Such an imager could then be used with or without an image intensifier depending upon the amount of light energy available and the exposure time desired.

Such an imaging arrangement may include a beam splitting arrangement that derives at least two beams of electromagnetic radiation from a single incident beam of electromagnetic radiation. The arrangement may further perform colour separation to provide a colour imaging device. The individual colours may be gated but, more likely all of the colours from a particular image in time will be gated together. In one dimension, therefore, the beam splitting arrangement is chromatic. The beam splitting arrangement may then be achromatic in the orthogonal dimension to enable a high speed imaging system to be provided. Colour separation can be performed in a number of different ways, for example using colour filters.

The gating may be performed by a Kerr or Pockel cell or other "passive" optical device.

Accordingly, the present invention further provides an imaging arrangement for two dimensional optical data represented by an incident beam of electromagnetic radiation, the arrangement comprising: means for splitting the incident radiation beam into a plurality of beams, means for gating and converting the beams into image data, wherein the means for gating and converting the beam into image data includes a single electro-

optic device having independently-gated portions corresponding to each of the plurality of beams.

The invention also provides a method of imaging two dimensional optical data represented by a beam of electromagnetic radiation, the method comprising:

splitting the radiation beam into a plurality of beams;

gating the plurality of beams;

converting the gated beams into image data;

wherein the gating of the plurality of beams is performed using a single electro-optic device having independently-gated portions corresponding to each of the plurality of beams.

It is a further object of the present invention to provide a method and apparatus of generating a plurality of images N from one input image which apparatus is suitable for use with the other aspects of the present invention.

High quality beam-splitting arrangements are difficult to design and expensive to produce. A beam-splitter which provides four images and having a quality suitable for higher speed photographic applications might typically cost £5000 per item.

According to a further aspect of the invention, therefore, there is provided apparatus for providing a plurality of images N from one input image, the apparatus comprising: an input objective lens for transmitting the input image to an input of a reflecting tunnel; a reflecting tunnel having an input and output between which are provided at least two reflecting planes, each of which reflecting planes is orthogonal to any adjacent reflecting planes; and an output objective lens for receiving the output images from the reflecting tunnel.

By using a reflecting tunnel to generate the multiple images an extremely cost-effective beam-splitter is provided. Generally speaking, the reflecting planes will be parallel to

the optical axis. Two, three or four reflecting planes are provided in dependence upon the number of images required as discussed more fully below.

The reflecting planes may be inwardly-facing mirrors or they may be the boundaries of a single block of glass (or other optical material) within which there is total internal reflection.

The cross-section of the reflecting tunnel may be rectangular or square.

The dimensions of the reflecting tunnel may be calculated in accordance with a method of manufacturing apparatus for providing a plurality of images N from one input image, the method comprising: determining an integer K greater than one such that  $K^2 \geq N$ ; selecting an input objective lens having f number (F/No) and image height H values; selecting a material for a reflecting tunnel which material has a refractive index RI; determining the minimum length L of the reflecting tunnel from the equation:  $L = K \times (F/\text{No}) \times H \times RI$ ; constructing a tunnel having height H and a length of L or greater; arranging the input objective lens at a first end of the reflecting tunnel; and arranging an output objective lens at a second end of the tunnel.

The variable K is the array size and denotes the number of images on one side of the output array. If K = 3, therefore, there will be nine images in the output array for a four-sided tunnel. Consequently, K<sup>2</sup> must be selected to be greater than or equal to N. The length L of the reflecting tunnel can then readily be derived from the equation above.

The present invention also provides an electro-optic device for generating a plurality of gated images N from one input image, the apparatus comprising: an input objective lens for transmitting the input image to an input of a reflecting tunnel; a reflecting tunnel having an input and an output between which are provided at least two reflecting planes, each of which reflecting planes is orthogonal to any adjacent reflecting planes; an output objective lens for transmitting light from an output of the reflecting tunnel to

an electro-optic device; and an electro-optic device comprising a photosensitive surface which surface is arranged to comprise a plurality of independently-gatable portions.

An extremely cost-effective electro-optic device is thus provided in which the beam splitting and the gating of the images is still of high optical quality but at considerably reduced prices compared with the precision optical and multiple camera arrangements of the prior art.

While arrangements and methods are described herein in the context of visible light, it will be understood that the present invention is equally applicable to ultraviolet (UV) and infra-red (IR) radiation.

The present invention will now be explained and described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a schematic diagram of an imaging system according to an embodiment of the invention,

Figure 2 shows a schematic plan view of the photocathode of the image intensifier shown in Figure 1,

Figure 3 shows an exemplary set of gate trigger signals for use with the arrangement shown in Figures 1 and 2,

Figure 4 shows an exemplary embodiment of the beam splitter optics from Figure 1,

Figure 5 shows a schematic plan view of an image intensifier according to an embodiment of one aspect of the invention and for use with an imaging system according to another aspect of the invention,

Figure 6 shows a schematic diagram of an imaging unit of the present invention applied with a colour-separating beam splitter to provide a high speed colour imaging system,

Figure 7 shows an end view of an optical beam splitter for use in the embodiment shown in figure 5,

Figure 8 shows a simple schematic diagram illustrating the principle of a beam-splitter in accordance with the present invention,

Figure 9 shows a more detailed diagram of the beam splitter in which a number of ray lines are shown,

Figure 10 shows a diagram of a part of the beam splitter illustrating how the length of the reflecting tunnel is calculated,

Figure 11 shows a diagram of a relay lens for use with the beam splitter, and

Figure 12 shows some components of an image intensifier according to an embodiment of the invention.

In Figure 1 light from an object OB passes through a conventional lens CL and enters a beam splitter BS which will be described in more detail subsequently. The beam splitter provides four identical images to an image intensifier II. It is assumed for the time being that the beam splitter is achromatic, in other words it effects no colour separation. The four images fall on the image intensifier to coincide with individually gated portions GP of the intensifier. These may be readily provided by controlling the deposition of the conductive material applied to the photocathode to reduce its resistance.

By gating the individually gatable portions of the image intensifier in sequence, four different, intensified images are supplied to a camera CM, for example a solid state

imager such as a CCD camera. Between the image intensifier and the camera a relay lens or fibre optic block (not shown) will typically be provided. The time resolved imaging of an event is thus recorded by the different positions of the image on the camera surface. Such a camera may comprise a CCD47-20 image sensor which is available from EEV of Waterhouse Lane, Chelmsford, Essex CM1 2QU, England. This sensor has an image area of 13.3mm by 13.3mm with an image format of 1024 x 1024 pixels. Thus, each of the four images may be recorded with a resolution of up to 512 x 512 pixels. By altering the gating signals applied to the image intensifier and the beam splitter optics it would be possible to record a pair of images at up to 1024 x 512 resolution. The readout of the image information can be performed in traditional manner.

Typically the sensor will be cleared prior to an imaging "run". If the event sought to be recorded did not occur during the run then the image information may be discarded or overwritten. The triggering of the sensor may be performed at the start of the event or, where the radiation levels at the start of an event may fail to trigger recording, using a "post-trigger" technique as described in European Patent Application EP 0701185A1. Briefly, such a technique records continually until a trigger signal "freezes" the data obtained for the previous few frames.

A segmented CCD approach may have separate "erasing" sections to facilitate this technique or use techniques akin to the ISIS CCD's etc., i.e. a means of "charge dumping" as a term used in the art. See, for example, International Patent Application WO97/43788.

Figure 2 shows a plan view of the photocathode of the image intensifier shown in Figure 1. This may have a diameter of, for example, 18mm or 40mm. The photocathode is typically a high resistance layer. In "static" (ungated) applications this causes no problems because the necessary (small) current for the electron beam can be supplied quickly enough from the periphery to all of the points on the photocathode. In gated applications, however, it is necessary to supply and remove the charge more quickly,

i.e. to charge the photocathode PC capacitance. This can result in “irising” where the centre of the photocathode lags the periphery despite the source of charge having added or removed charge from the periphery of the photocathode. A known solution to this problem is to provide an additional conductive layer next to the photocathode. Such a layer is typically made from Nickel or Antimony.

In the present embodiment this conductive layer is divided into four equal segments. Between each of the segments is a small gap of 1mm or less shown by a dark line (it could be more but there will be a consequent loss of control over the gating in the gap and waste of imaging area). Each of the segments is connected to receive a respective gating pulse GP1, GP2, GP3 and GP4. The total resistance across each gap between segments will typically be  $5\text{k}\Omega$  or more. The resistance across each segment will typically be  $200\Omega$ . Capacitive coupling to the segments may be used instead.

Figure 3 shows a possible set of gating pulses that could be used with the arrangement of Figure 1. These pulses typically comprise an “off” level of approximately +50V (relative to the microchannel plate input) and an “on” level of -200V. In the example shown in figure 3, the four segments of the photocathode are triggered in turn for a short duration and there is an optional small delay before the next segment is triggered. The trigger duration may typically be as short as 2-3 ns but may be as long as 100 $\mu$ s or much longer. A typical extinction ratio is  $10^{10}$  so there is an excellent distinction between the “on” and “off” states.

While resettable (erasable) CCD cameras are known they have previously only been available in which the whole of the imaging area is erasable. One such camera could be used for each of the separated images. By typically applying the anti-blooming structure in a segmented fashion as described for the photocathode above, a segmented CCD may be provided that allows erasure on a per-segment basis. The segmented CCD would appear as shown in Figure 2 but with reset/erase lines instead of gate-pulse lines. This may then be used in conjunction with the segmented image intensifier to provide a continuous imaging system. The relevant segment of the CCD camera is cleared by a

reset pulse before the relevant segment of the image intensifier is gated so that the relevant part of the CCD is cleared by the time it is exposed. Typically, the pulse timing applied to clear the portion of the CCD will be that used to gate the portion of the image intensifier one or two exposure times previously. Other periods of delay between clearing and exposing the portion of the CCD may be used subject to the constraint that the CCD portion is cleared prior to exposure (it typically takes approximately 1 $\mu$ s to clear the CCD with a vertical anti-blooming structure).

Such an arrangement may be used to provide a continuous imaging system provided with a "post-trigger" arrangement described in the European Patent Application identified above.

A CCD camera may itself be provided with triggering means that operate upon a number of discrete segments of the camera in accordance with the present invention. Such a camera may further be provided with erasing means as discussed above. Typically one would segment an anti-blooming structure for erasure control and also any electronic gating techniques that may be employed (interline transfer regions, in situ image storage (ISIS) devices etc.).

Figure 4 shows an elevational view of an optical system for providing beam splitting, in this example into four different images in two rows of two. A four faceted achromatic prism is used as the actual beam splitting device.

An input optical signal I/P is applied to the left of the device as shown in the Figure. At the right hand side of the figure is the photocathode PC of the image intensifier II shown in figure 1. The total length TL of the optical system is approximately 355mm. The flange distance FD is the distance between the final optical element and the photocathode of the image intensifier. The straight line to the left of the figure is the focal plane FP for the input light. The input beam is subject to a number of conventional lenses CL to achieve collimation prior to being applied to the achromatic prism AP. This collimation is loosely based on a Petzval lens. In this instance the prism

is a four-sided truncated pyramid. Other shapes will be required in different circumstances, for example the eight times three faceted, colour-splitting optical element required for use with an intensifier shown partly in Figure 7 which will be discussed later. The optical elements to the right of the prism form an objective lens which collects the collimated light deviated by the prism and is similar to a conventional photographic lens such as a high performance, high numerical aperture objective lens which offers very low vignetting. The collimation lens and the objective lens as a whole form a relay lens (which includes beam splitting or colour separation).

The beam splitter, in particular the achromatic prism will need careful design to ensure separation of, and equal intensity for, each of the split beams. A beam splitting arrangement meeting such requirements is well within the competence of the relevant optical engineer. Other beam splitting techniques are equally applicable.

The important features for such techniques are that there is even performance across the field of view and that the input light is accurately collimated prior to being applied to the prism.

The optical system comprises a collimator lens comprising the elements prior to the beam splitter AP followed by an objective lens system to throw the image onto the photocathode PC.

A particularly preferred beam splitter for use with the electro-optic device is shown in Figure 8. In Figure 8 an image (illustrated here as a capital letter "F") passes through a conventional objective lens 12, which is preferably a high aperture lens. Light from this lens passes to a reflecting tunnel 14 whose cross section is also shown. The reflecting tunnel 14 has four reflecting planes 14.1, 14.2, 14.3 and 14.4 each of which is orthogonal to the adjacent reflecting planes. The reflecting tunnel may comprise four inwardly-facing mirrors or a block of optical material whose faces provide total internal reflection within the tunnel. Light emerging from the tunnel 14 is applied to an output objective lens 16 (see Figure 11) which is preferably a wide angle, short focal length

lens which focuses the multiple images from the output of the tunnel 14 onto an electro-optic device 18.

To the right of Figure 8 is the pattern of multiple images applied to the electro-optic device. Nine images are shown in a 3 x 3 array but larger numbers of images are possible as will be discussed later. The maximum number depends upon the pixels available on the CCD and hence the number of pixels in image, of the array and the amount of detail required for analysis. As can be seen in the figure, the adjacent images are inverted with respect to one another but this can readily be taken care of in subsequent processing. For example, in the case of a charge coupled device (CCD) camera the relevant data can be re-ordered when read out from the device.

The CCD camera could be of any type or form, high speed, high resolution etc. A colour system using different filters is described below.

While the image tunnel 14 is shown as having four reflecting planes, as a minimum, two reflecting planes which are mutually orthogonal can be provided. The number of output images along each side of the array is denoted as K. When K = 3 and two reflecting planes are provided there will be four object images. When K = 3 and three reflecting planes are provided then there will be six output images.

Figure 9 shows a more detailed version of the simple schematic diagram shown in Figure 8. A high Numerical Aperture (NA) objective lens 12 comprises five separate lenses 12.1., 12.2 .... 12.5. The design and construction of such a lens is well within the competence of the relevant skilled person. Typical characteristics of such a lens would be: 50 mm F/1.8. Light rays from an image (not shown) are conveyed by this lens to the reflecting tunnel 14.

While a lens 12 (Figure 8) and a high N.A. objective (Figure 9) have been described, these are not essential. What is important for the tunnel beamsplitter (and other types) is that the Prime Image (Figure 9) has a high N.A. value (in other words is well

scattered). If the input is highly collimated there will be insufficient reflection off the sides of the tunnel.

As a further alternative an ordinary (unsegmented) image intensifier with fibre-optic output may be used as the input image plane, in other words replacing the real image formed by the conventional objective lens. In this case the fibre optic block at the output of the intensifier is made to coincide with the Prime Image (Figure 9) for direct coupling to the tunnel. This ordinary intensifier may also give UV or IR, XRAY to visible conversion, more gain and so on but, importantly, the output at its fibre optic screen will be high N.A. The N.A will be 1 or very close to 1 with the consequence that relay lens systems would likely be inefficient. Direct coupling to the tunnel is then ideal because a tunnel would be very efficient if configured for  $f/1$  or less, as is possible (see below). Indeed all that the tunnel requires is that the image at the entrance to the tunnel is of high N.A. Also where the source is ultraviolet or a conversion to ultraviolet has been effected the tunnel is ideal. This beamsplitter is intrinsically UV capable because mirrors reflect UV light while, by contrast, a prism would need to be designed specifically.

The output objective lens 16 or schematic relay lens may be an "off the shelf" macro focus lens or a custom designed lens as will be described with reference to Figure 11.

As can be seen from the Figure, the light from the input image is reflected within the tunnel 14 to provide the required number of output images. The number of images will be defined by the maximum entrance angle of rays from the objective lens entering the mirror tunnel; the maximum angle of reflection of the mirror system (total internal reflection in the case of a solid block of optical material) and the field of view of the output objective lens. The relevant calculations will be described below with reference to Figure 10.

Figure 10 shows a schematic view of the reflection of the light beams within the reflecting tunnel 14 having four reflecting planes. The height of the tunnel is shown as

H and the length of the tunnel is shown as L. If the total length of the reflecting tunnel shown is used then a 7 x 7 array of output images will be produced. This length is also denoted as L7. Two shorter lengths are denoted as L3 and L5. These correspond with the length of tunnel required to provide a 3 x 3 array and a 5 x 5 array respectively. Because there will always be a straight-through or prime image in the centre of the output image array, each side of the array must always comprise an odd number of images. When all four sides are present, the beam splitter can be arranged to provide values of N equal to 9, 25, 49 and so on. If only three sides are present then the images along one side of the array are omitted. When K = 3 then six images will be provided. If only two sides are present then the images along two sides of the array are omitted. When K = 3 then four images will be provided.

The length of tunnel required can be calculated from the following equation:

$$L = K \times (F/\text{No}) \times H \times RI$$

where K equals the number of output images along one side of the array, i.e. 3, 5, 7, etc.

F/No = input OG Aperture Ratio (Aperture ratio=Focal length of lens/Entrance pupil diameter and OG = Objective Glass or just Objective)

H = input OG image height

RI = refractive index, i.e.: 1.0 for mirror tunnel or

- = 1.492 for Acrylic
- = 1.517 for BK7 Glass (Schott)
- = 1.567 for Styrene
- = 1.585 for Polycarbonate

The field of view of the Output Relay lens is:-

$$\text{FOV} = \pm \tan^{-1} (0.7071/\text{Aperture Ratio})$$

Figure 11 shows a relay lens having the following characteristics:

- (a) External Aperture stop positioned very near to the end of the tunnel.

- (b) No vignetting
- (c) uniform performance
- (d) iris at stop position

The figure is to scale and, in absolute terms, is just under twice actual size.

The above has assumed that the tunnel has a square cross section. However, the invention is equally applicable to a rectangular cross section with one dimension being W and the other being H. The field of view becomes:-

$$\text{FOV} = \tan^{-1} \sqrt{(H^2 + W^2)} / (2 \cdot F/\text{No.} \cdot H)$$

where H is the larger of the two cross section dimensions. When the tunnel has a square cross section then H = W and the formula simplifies to that given above.

Figure 5 shows a plan view and a side view of an image intensifier having eight individually triggerable segments in two rows of four. The plan view shows the segments or gatable portions GP. The side view shows that the intensifier is of conventional construction - for example using a copper press-off technique (cold copper seal) as is well known. The intensifier comprises an input window IW, onto the internal surface of which are deposited, using a mask, a number of individual areas of semi-transmitting conductive material, to create the gated portions GP which are connected to conducting strips CS 1, CS 2, CS 3, etc., on the edge of the input window. The input window is joined to a metal ring by an insulating seal IS thereby allowing each of the conducting strips to remain electrically isolated. A photocathode surface PC is deposited over the surface of the input window and the semi-transmitting conductive areas.

Beyond the photocathode and isolated from it by a thin layer of vacuum is the microchannel plate MP of conventional construction which is isolated from a phosphor screen PS by another thin layer of vacuum. The phosphor screen is deposited on the

internal surface of the output window OW. The output window if manufactured from fibre optics may directly abut the CCD or may be separated therefrom by a fibre optic block. In its simplest form the construction of an image intensifier in accordance with the invention is entirely conventional with the exception of the masking applied to the conductive layer adjacent the photocathode and the connections around the edge of the input window. The unit operates in an entirely conventional manner with the exception of the individually gateable portions. Note that the gap between the segments is a conventional photocathode and is also light sensitive.

The intensifier may be made in any size format, for example standard 18mm or 40mm. Figure 12 shows a complete 40mm intensifier (left) and an 18mm intensifier each having four gated sections. Also shown is a mask for use in depositing the low resistance material on the photocathode of an intensifier having eight gated sections.

Figure 6 shows a plan view of a photocathode of an alternative embodiment of the present invention. The photocathode is shown divided into 24 segments R1, G1, B1, R2 and so on up to R8, G8 and B8. In this embodiment the photocathode is segmented into eight rectangular portions which correspond with the numbers 1 to 8 in the figure. This intensifier is intended to be used in a three-colour imaging system. The beam splitter optics are arranged to provide eight spatially displaced but similar beams in one dimension. In the direction at right angles (orthogonal) to that direction, however, a colour dependent effect is provided. The three colour elements of each beam are thus separated for independent detection. Again, the beam splitting optics required to provide this effect is readily obtainable by the relevant engineer simply by adding colour filters to the prism or in any of the optical beams. By gating the eight portions of the intensifier in turn a high speed, eight image, colour imaging arrangement can be provided. Of course, the invention is not restricted to the straightforward colour split between red, green and blue but split colours differently according to the application, i.e. perhaps two colours plus monochrome. Additionally it may be desired, for example, to separate the visible spectrum from the near infra-red. Ultra-violet sensing may also be employed.

Any CCD camera may be used to image the segmented intensifier output, i.e. at resolutions from conventional video through 1K x 1K to 2K x 2K or more pixels. Not necessarily being rectangular, i.e. EEV CCD 47 is 2048 x 1024 pixels.

Figure 7 shows an end view of an optical beam splitting element for use with one of the aspects of the invention. On one side there are four facets providing four different beams in that dimension (there may be further facets in the dimension perpendicular to the plane of the paper). Between each facet is a small strip LS of light blocking material to prevent the images from being distorted by the beam splitting element at their edges. Other profiles are, of course, possible to provide different numbers of rows of split images. Care must be taken to ensure that equal amounts of energy (or nearly so) are transferred into the split beams for consistent operation between the different image portions of the arrangement. Small differences can be allowed for in the subsequent processing of the image signals.

Of course the present invention is not limited to image intensifiers and optical sensors having four, six or eight portions. It is easier but not essential for the portions to each be accessible from the periphery of the device since this facilitates electrical connection. If a three by three arrangement were provided, for example, the electrical connection to the centre portion might be routed between one of the peripheral portions. This might have adverse effects on the speed of operation or on the completeness of the image(s) captured on either side of the electrical line (see the photocathode mask in Figure 12 for providing eight gateable portions). Alternatively, capacitive coupling may be employed by a mesh or conductive plate (semi transparent) on the external surface of the photocathode window to gate the otherwise unconnected segment.

Note that in the construction of the intensifier as detailed above, the narrow stripe between two segments, being normal photocathode, will enable the whole intensifier to operate as a single intensifier if this be desired, the stripe appearing as a lighter band (there being no semi transparent material in front of the photocathode in this region) but

will otherwise leave the image unaffected. This may have advantages for variable resolution systems, i.e. in a four segment system with a 1K x 1K CCD, one image at 1K x 1K, two images at 1K x 512 or four images at 512 x 512 pixels - with the use of the appropriate prism/beamsplitter.

Optical gating using Kerr or Pockel cells, for example, may alternatively be used in the imaging arrangement.

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## AMENDED CLAIMS

[received by the International Bureau on 10 January 2000 (10.01.00);  
original claims 1 and 16 amended; new claim 33 added;  
remaining claims unchanged (3 pages)]

1. An electro-optic device comprising a photosensitive surface which surface is arranged to comprise a plurality of independently-gatable portions each portion being responsive to an image signal.
2. An electro-optic device as claimed in claim 1, wherein the device comprises an image intensifier.
3. An electro-optic device as claimed in claim 2, wherein the image intensifier comprises a segmented photocathode.
4. An electro-optic device as claimed in claim 3, wherein the segmented photocathode comprises a photocathode layer and a segmented conductive layer adjacent the photocathode layer.
5. An electro-optic device as claimed in claim 1, wherein the device comprises a solid-stage imager.
6. An electro-optic device as claimed in claim 5, wherein the solid state imager comprises segmented imaging sections.
7. An electro-optic device as claimed in claim 5 or claim 6, wherein the solid state imager further comprises erasing means for erasing an image corresponding to one of the plurality of beams.
8. An electro-optic device as claimed in claim 5 or claim 6, wherein the solid state imager further comprises overwriting means for overwriting an image corresponding to one of the plurality of beams.
9. An imaging arrangement for two dimensional optical data represented by at least two beams of electromagnetic radiation, the arrangement comprising means for gating

and converting the beams into image data which means for gating and converting the beams into image data includes a single electro-optic device as claimed in any one of the claims 1 to 8 wherein the independently gated portions correspond to each of the at least two beams of electromagnetic radiation.

10. An imaging arrangement as claimed in claim 9, further comprising means for splitting an incident beam of electromagnetic radiation into at least two beams of electromagnetic radiation for application to the means for gating and converting the beams.

11. An imaging arrangement as claimed in claim 10, wherein the means for splitting the incident beam into a plurality of beams comprises chromatic means for splitting each of the plurality of beams into a plurality of differently-coloured beams.

12. An imaging arrangement as claimed in claim 11, wherein the independently-gated portions of the means for gating and converting the beams into image data correspond with each of the plurality of differently-coloured beams.

13. An imaging arrangement as claimed in any one of the claims 9 to 12, further comprising means responsive to an event for storing converted image data which was converted before the event.

14. An imaging arrangement for two dimensional optical data represented by an incident beam of electromagnetic radiation, the arrangement comprising:

means for splitting the incident radiation beam into a plurality of beams,  
means for gating and converting the beams into image data,

wherein the means for gating and converting the beam into image data includes a single electro-optic device having independently-gated portions corresponding to each of the plurality of beams.

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15. A method of imaging two dimensional optical data represented by a beam of electromagnetic radiation, the method comprising:

splitting the radiation beam into a plurality of beams;

gating the plurality of beams;

converting the gated beams into image data;

wherein the gating of the plurality of beams is performed using a single electro-optic device having independently-gated portions corresponding to each of the plurality of beams.

16. Apparatus for providing a plurality of images N from one input image, the apparatus comprising:

means for transmitting the input image to an input of a reflecting tunnel;

a reflecting tunnel having an input and output between which are provided at least two reflecting planes, each of which reflecting planes is orthogonal or parallel to any adjacent reflecting planes; and

an output objective lens for receiving the output images from the reflecting tunnel.

17. Apparatus as claimed in claim 16, wherein the reflecting tunnel is provided with four reflecting planes.

18. Apparatus as claimed in claim 16 or claim 17, wherein the planes of the reflecting tunnel are parallel to an optical axis between the input objective lens and the output objective lens.

19. Apparatus as claimed in any one of claims 16 to 18, wherein the cross-section of the reflecting tunnel is square.

20. Apparatus as claimed in any one of claims 16 to 19, wherein the length L of the reflecting tunnel is at least L where

$$L = K \times (F/No) \times H \times RI$$

where  $K^2 \geq N$

F/No = input OG F/No

H = height of the tunnel and

RI is the refractive index for the reflecting tunnel.

21. Apparatus as claimed in claim 20, wherein K is an odd integer greater than one.
22. Apparatus as claimed in any one of the claims 16 to 21, wherein the reflecting planes of the reflecting tunnel comprise plane mirrors.
23. Apparatus as claimed in any one of the claims 16 to 22, wherein the reflecting planes of the reflecting tunnel comprise surfaces of the tunnel which comprises optical material.
24. A method of manufacturing apparatus for providing a plurality of images N from one input image, the method comprising:
  - determining an integer K greater than one such that  $K^2 \geq N$ ;
  - selecting an input objective lens having f number (F/No) and image height H values in response to input signals having a low numerical aperture;
  - selecting a material for a reflecting tunnel which material has a refractive index RI;
  - determining the minimum length L of the reflecting tunnel from the equation:
$$L = K \times (F/\text{No}) \times H \times RI;$$
  - constructing a tunnel having height H and a length of L or greater;
  - arranging the input objective lens at a first end of the reflecting tunnel; and
  - arranging an output objective lens at a second end of the tunnel.
25. Apparatus as claimed in any one of the claim 24, wherein the reflecting planes of the reflecting tunnel comprise plane mirrors.

26. Apparatus as claimed in any one of the claim 24 wherein the reflecting planes of the reflecting tunnel comprise surfaces of the tunnel which comprises optical material.

27. A method as claimed in any one of the claims 24 to 26, wherein the output objective lens is a wide angle, short focal length objective lens.

28. A method as claimed in any one of the claims 24 to 27, wherein the cross section of the tunnel is square.

29. A method as claimed in any one of the claims 24 to 28 wherein the tunnel has four reflecting planes.

30. An electro-optic device for generating a plurality of gated images N from one input image, the apparatus comprising:

means for transmitting the input image to an input of a reflecting tunnel;  
a reflecting tunnel having an input and an output between which are provided at least two reflecting planes, each of which reflecting planes is orthogonal to any adjacent reflecting planes;

an output objective lens for transmitting light from an output of the reflecting tunnel to an electro-optic device; and

an electro-optic device comprising a photosensitive surface which surface is arranged to comprise a plurality of independently-gatable portions.

31. Apparatus as claimed in claim 30, wherein the electro-optic device comprises an image intensifier.

32. Apparatus as claimed in claim 31, wherein the image intensifier comprises a segmented photocathode.

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33. Apparatus as claimed in claim 2 or claim 31, wherein the image intensifier comprises a photocathode which photocathode is controlled capacitively by a segmented, external electrode.

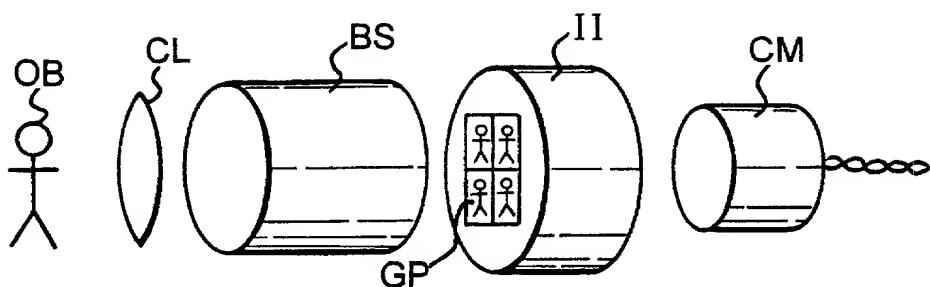


Fig. 1

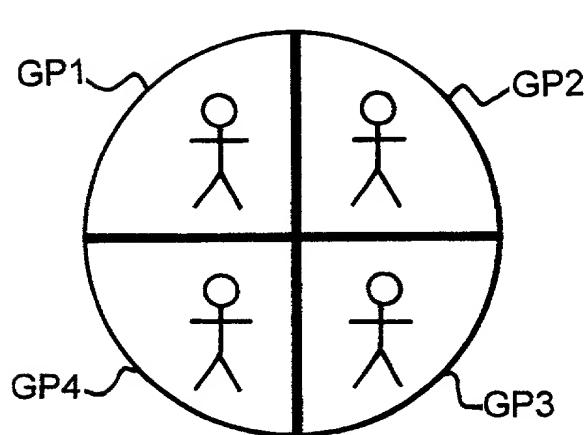


Fig. 2

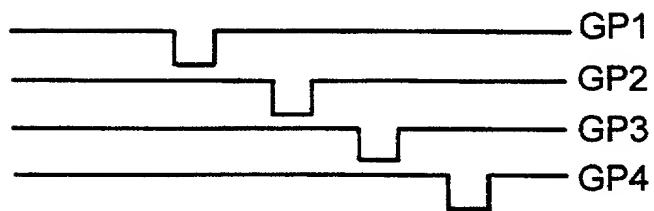


Fig. 3

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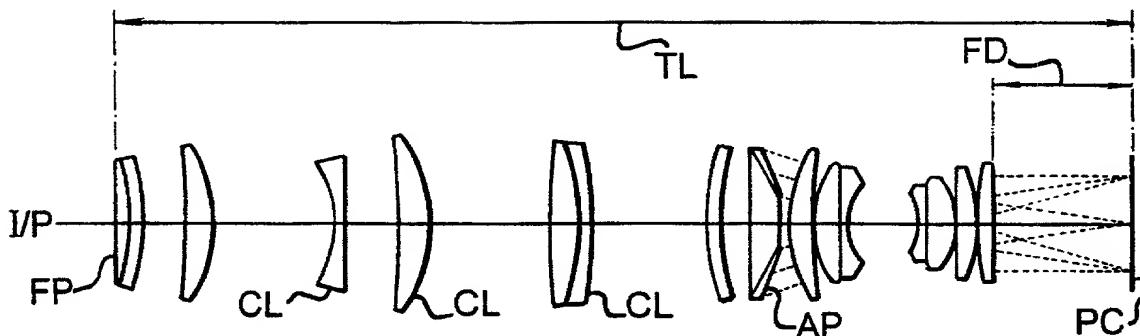


Fig. 4

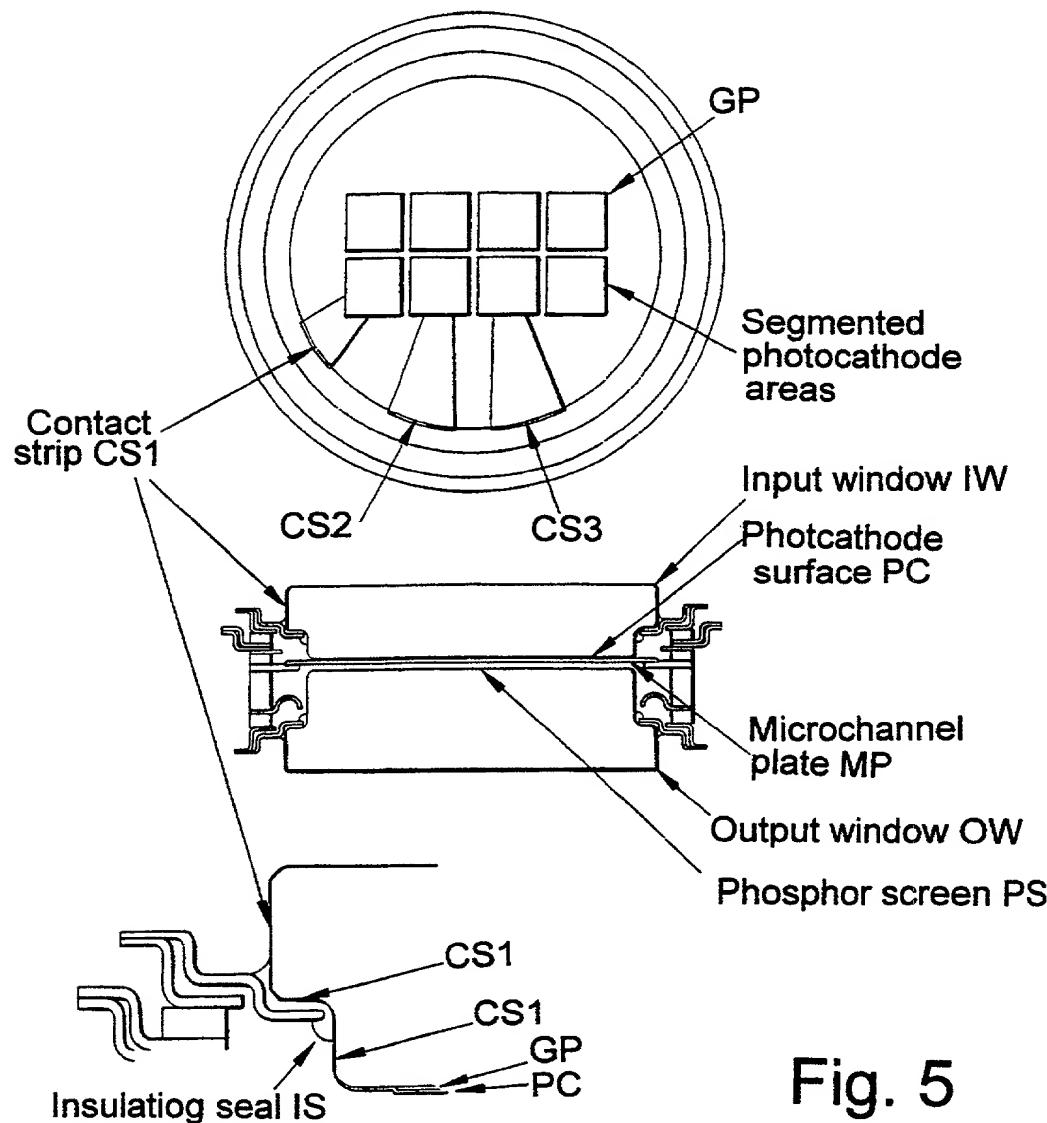


Fig. 5

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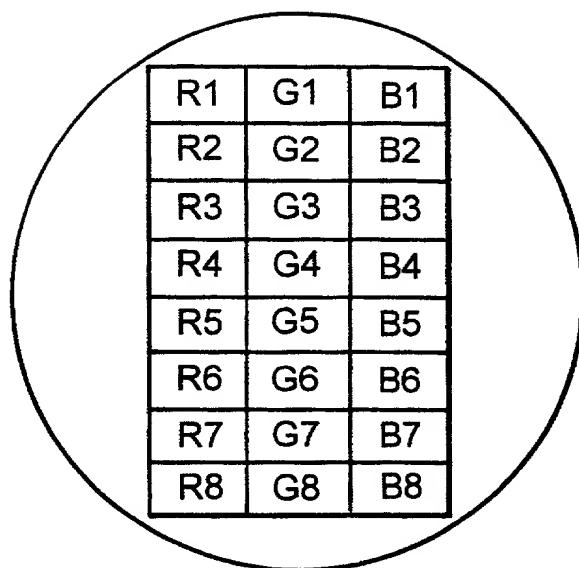


Fig. 6

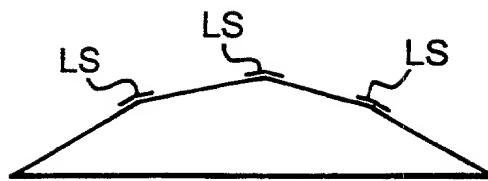


Fig. 7

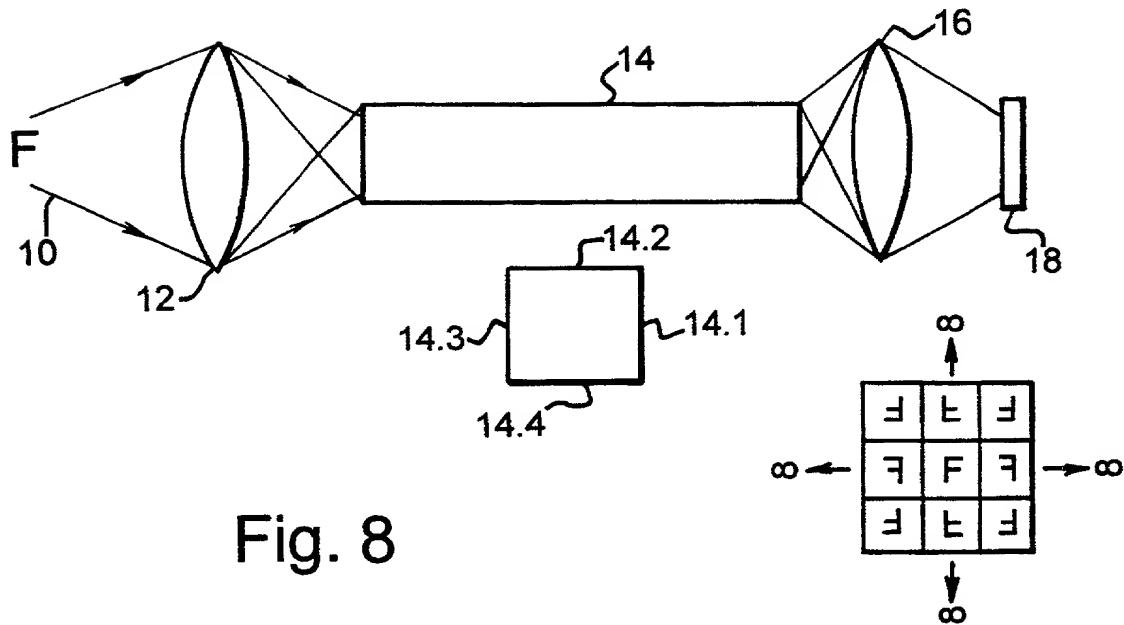


Fig. 8

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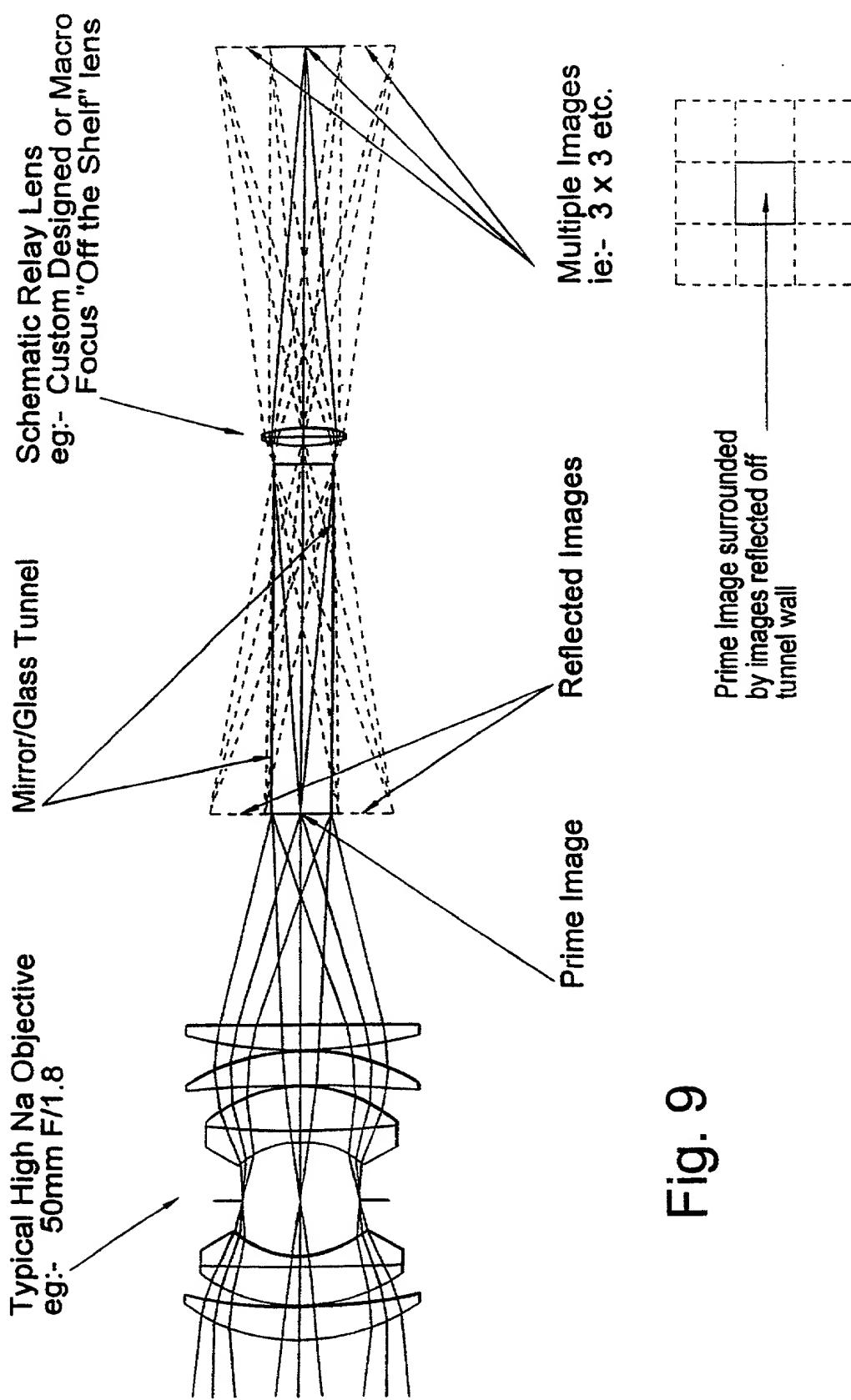
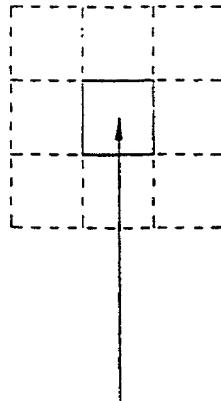
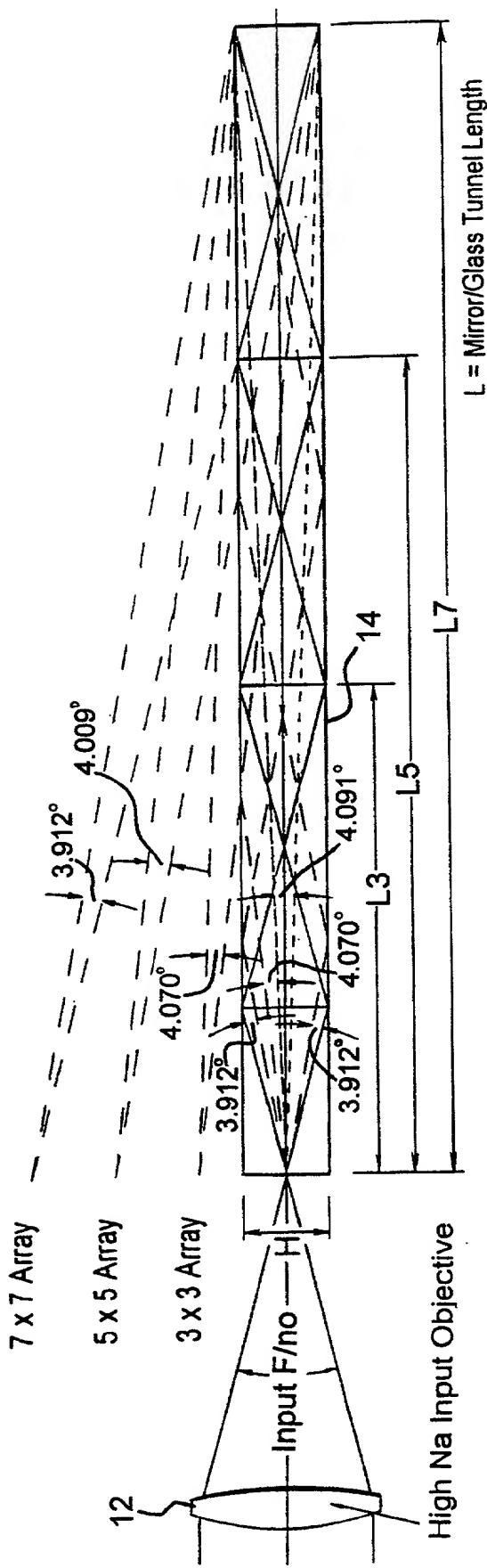


Fig. 9





L = Mirror/Glass Tunnel Length

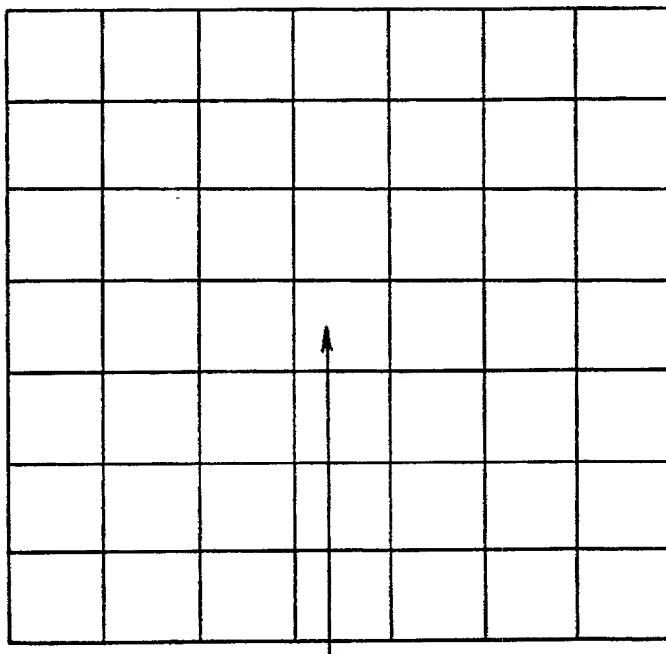
Where:-

Length  $L = K \times (F/\text{No}) \times H \times RI$

K = Array Size ie. 3, 5, 7 etc  
 $F/\text{No} = \text{Input OG } F/\text{No}$   
 $H = \text{Input OG Image Height}$   
 $RI = 1.0$  for Mirror Tunnel or  
" = 1.492 for Acrylic  
" = 1.517 for BK7  
" = 1.567 for Styrene  
" = 1.585 for Polycarbonate

Output  $F/\text{No} = L/(h \times RI)$

Efficiency =  $((\text{Input } F/\text{No}) / (\text{Output } F/\text{No}))^2$



Prime Image surrounded  
by images reflected off  
tunnel wall

Fig. 10

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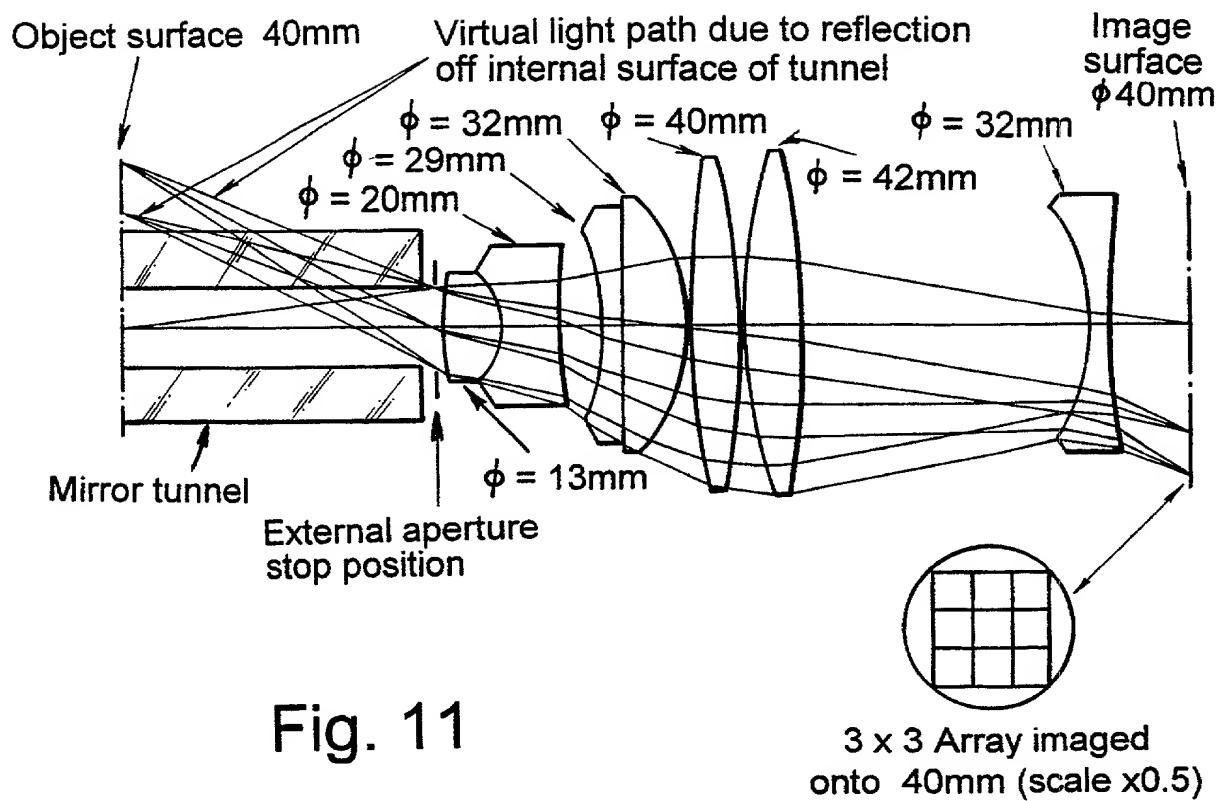


Fig. 11

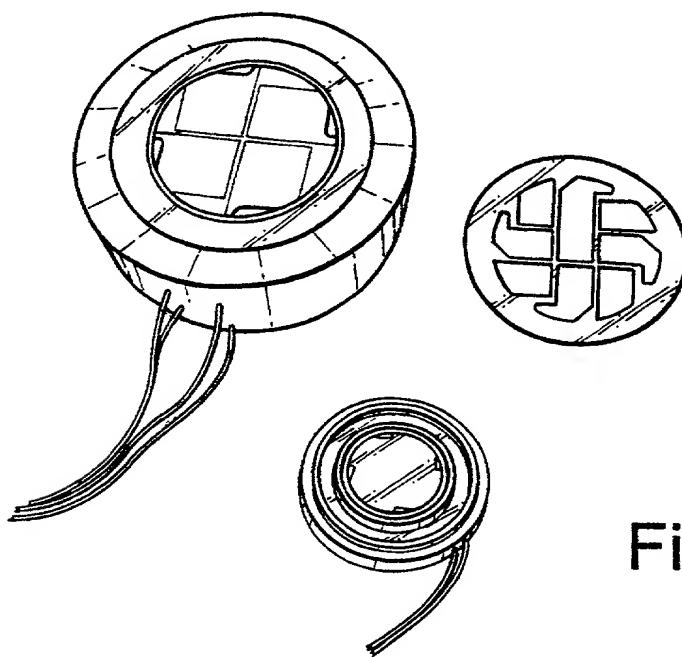


Fig. 12

## DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that: My residence, post office address and citizenship are as stated below next to my name; I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

## IMAGING ARRANGEMENT AND METHOD

the specification of which:

is attached hereto; or

was filed as United States Application Serial No. 09/701,559  
on December 5, 2000, and was amended on \_\_\_\_\_  
(if applicable); or

was filed as PCT International Application Number PCT/GB99/01763  
on June 4, 1999 and was amended on January 10, 2000  
(if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate or § 365(a) of any PCT international application(s), designating at least one country other than the United States, listed below and have also identified below any foreign application(s) for patent or inventor's certificate, or any PCT international application(s) having a filing date before that of the application(s) of which priority is claimed:

Country	Application Number	Date of Filing	Priority Claimed Under 35 U.S.C. 119
United Kingdom	9812210.4	June 5, 1998	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
United Kingdom	9903428.2	February 15, 1999	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

Application Number	Date of Filing

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) or § 365(c) of any PCT international application(s) designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application(s) in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application(s) and the national or PCT international filing date of this application:

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TOTAL P. 68

Attorney Docket No.: 03042.01

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Attorney Docket No.: 03042.0060

Application Number	Date of Filing	Status (Patented, Pending, Abandoned)

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.